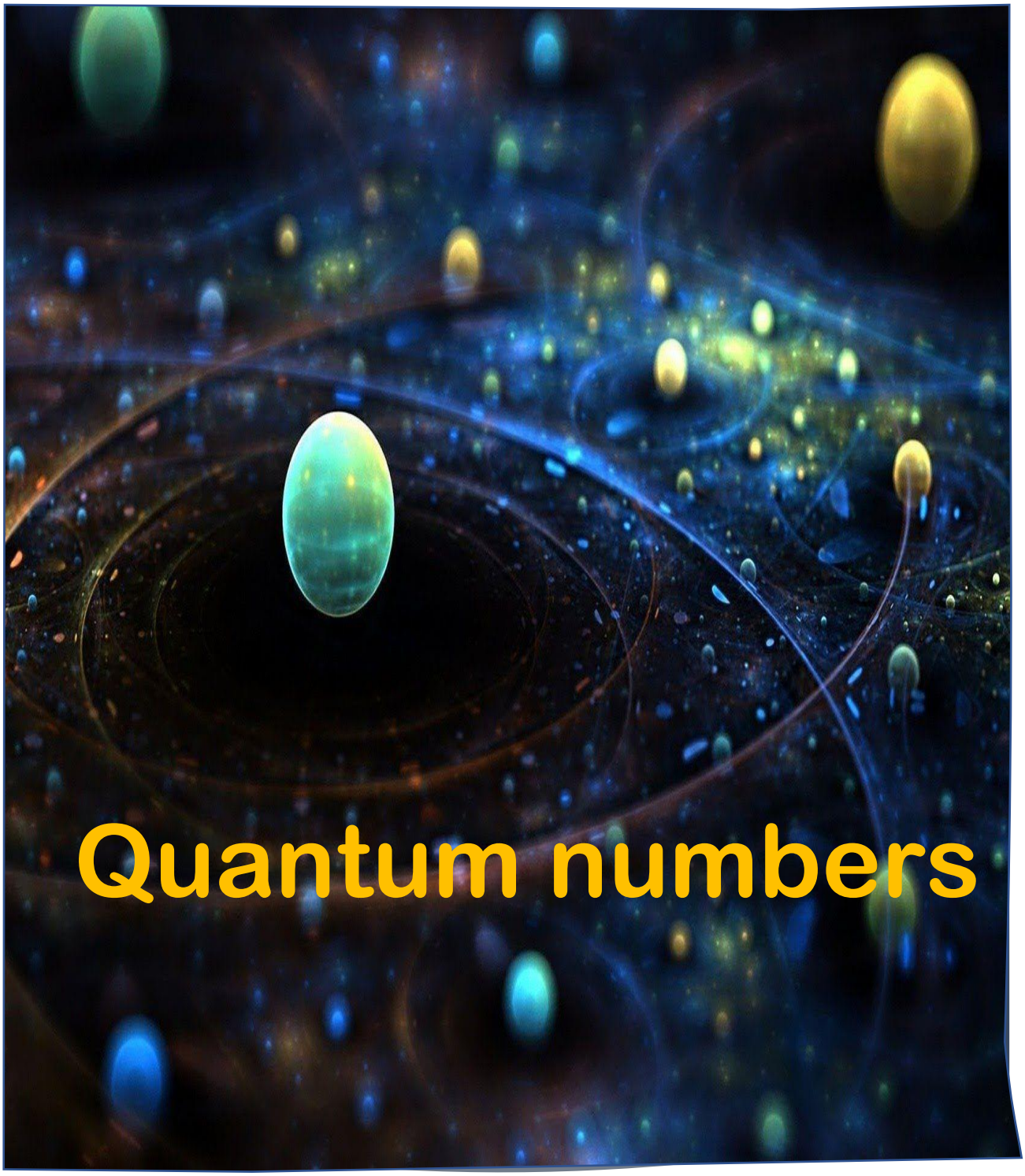

Quantum numbers

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Quantum numbers describe values of conserved quantities in the dynamics of a quantum system.

In the case of electrons, the quantum numbers can be defined as "the sets of numerical values which give acceptable solutions to the Schrödinger wave equation for the hydrogen atom".

In more general cases, quantum numbers correspond to eigenvalues of operators that commute with the Hamiltonian quantities that can be known with precision at the same time as the system's energy and their corresponding eigenspaces.

Together, a specification of all of the quantum numbers of a quantum system fully characterize a basis state of the system, and can in principle be measured together.

An important aspect of quantum mechanics is the quantization of many observable quantities of interest.

In particular, this leads to quantum numbers that take values in discrete sets of integers or half-integers; although they could approach infinity in some cases.

This distinguishes quantum mechanics from classical mechanics where the values that characterize the system such as mass, charge, or momentum, all range continuously.

Quantum numbers often describe specifically the energy levels of electrons in atoms, but other possibilities include angular momentum, spin, etc. An important family is flavor quantum numbers internal quantum numbers which determine the type of a particle and its interactions with other particles through the fundamental forces.

Any quantum system can have one or more quantum numbers; it is thus difficult to list all possible quantum numbers.

Principal quantum number

This describes the electron shell, or energy level, of an electron. The value of n ranges from 1 to the shell containing the outermost electron of that atom, that is

$$n = 1, 2, \ldots$$

Magnetic quantum number

This describes the specific orbital (or "cloud") within that subshell, and yields the *projection* of the orbital angular momentum *along a specified axis*:

$$L_z = m_\ell \hbar$$

Spin quantum number

This describes the spin (intrinsic angular momentum) of the electron within that orbital, and gives the projection of the spin angular momentum S along the specified axis:

$$S_z = m_s \hbar.$$

In general, the values of m_s range from $-s$ to s, where s is the spin quantum number, an intrinsic property of particles:

$$m_s = -s, -s + 1, -s + 2, ..., s - 2, s - 1, s.$$

Azimuthal quantum number

Also known as the (angular quantum number or orbital quantum number), this describes the subshell, and gives the magnitude of the orbital angular momentum through the relation

$$L^2 = \hbar^2 \ell (\ell + 1)$$

In chemistry and spectroscopy, $\ell = 0$ is called an s orbital, $\ell = 1$ a p orbital, $\ell = 2$ a d orbital, and $\ell = 3$ an f orbital.

The value of ℓ ranges from 0 to $n - 1$, so the first p orbital ($\ell = 1$) appears in the second electron shell ($n = 2$), the first d orbital ($\ell = 2$) appears in the third shell ($n = 3$), and so on:[2]

$$\ell = 0, 1, 2, \ldots, n - 1$$

Name	Symbol	Orbital meaning	Range of values	Value examples
Principal quantum number	n	shell	$1 \leq n$	$n = 1, 2, 3, \ldots$
Azimuthal quantum number (angular momentum)	ℓ	subshell (s orbital is listed as 0, p orbital as 1 etc.)	$0 \leq \ell \leq n - 1$	for $n = 3$: $\ell = 0, 1, 2$ (s, p, d)
Magnetic quantum number (projection of angular momentum)	m_ℓ	energy shift (orientation of the subshell's shape)	$-\ell \leq m_\ell \leq \ell$	for $\ell = 2$: $m_\ell = -2, -1, 0, 1, 2$
Spin quantum number	m_s	spin of the electron ($-\frac{1}{2}$ = "spin down", $\frac{1}{2}$ = "spin up")	$-s \leq m_s \leq s$	for an electron $s = \frac{1}{2}$, so $m_s = -\frac{1}{2}, +\frac{1}{2}$